1063

EVALUATION REPORT
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Evaluation of External Battery Power Supply for Bathyscaph TRIESTE

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U. S. NAVY ELECTRONICS LABORATORY, SAN DIEGO, CALIFORNIA
A BUREAU OF SHIPS LABORATORY

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THE PROBLEM

Determine the practicability and effectiveness of using lead-acid storage batteries as a power supply under high hydrostatic pressures and low temperatures such as are encountered in the deep sea. Also, determine the magnitude of any loss of capacity or decrease in discharge rate attributable to high pressures or low temperatures within the range found in the deep sea.

RESULTS

Lead-acid storage batteries were found to provide an effective and practical power source under pressures up to 16, 000 psi and temperatures down to 35° F. The lead-acid batteries are cheaper than the silver-zinc cells used and may be mounted externally to save cabin space.

RECOMMENDATIONS

1. Use externally carried lead-acid storage batteries as the primary power supply for the TRIESTE.

2. Extend the investigations reported herein to include other types of "wet" batteries for similar uses.

3. Initiate investigation to determine other areas of use for this type of power supply, such as unmanned buoys or ocean-bottom instruments.

ADMINISTRATIVE INFORMATION

Work was performed under SR004 03 01 (NEL L4-1) by members of the Services Department and Signal Propagation

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Division. The report covers work from May 1960, at Guam, through January 1961, at the Navy Electronics Laboratory, and was approved for publication 18 August 1961.

Grateful acknowledgment is made to E. W. Hutchison and Charles Hill of the U. S. Navy Electronics Laboratory, who designed the battery box used during Project NEKTON II, designed and constructed the test casings used in the tests presented in this report, and, along with C. M. Adams, EM1, were responsible for the major portion of the supervision of those tests. Thanks are also due A. B. Rechnitzer, LCDR R. D. Plunkett, and LT Don Walsh for their assistance in the tests and for a critical review of this report.

Previous NEL publications dealing with the bathyscaph and its operation are the following:

NEL Report 941, The 1957 Diving Program of the Bathyscaph TRIESTE, by A. B. Rechnitzer, 28 December 1959. UNCLASSIFIED

NEL Report 956, Evaluation of the Control Characteristics of Bathyscaph Ballast, by R. K. Logan, 11 February 1960. UNCLASSIFIED

NEL Report 1030, Investigation of Window Fracture in Bathyscaph, by J. C. Thompson, R. K. Logan, and R. B. Nehrich, 20 March 1961. UNCLASSIFIED

CONTENTS

TABLE

ILLUSTRATIONS

INTRODUCTION

This report discusses the suitability of lead-acid batteries for use as a power supply on the bathyscaph TRIESTE during decents into the hostile pressure and temperature environment of the deep sea. Further information concerning the bathyscaph itself and its operation is contained in another report.[1]

The bathyscaph is not, in some ways, a weight-limited vehicle. It has been designed with buoyancy to support additional ballast for deeper dives and the heavy KRUPP sphere. Operating in depths of 20,000 feet or less and utilizing the lighter TERNI sphere or cabin, the bathyscaph has buoyancy to support additional payload. The main problem is space limitation.

The power supply of the TRIESTE formerly consisted of small silver-zinc batteries. These were extremely expensive and occupied a large part of the available cabin space. An externally mounted power supply would free this valuable cabin space and greatly increase the power which can be carried. Only the limitations imposed by the structural space available to mount the power supply externally and by the weight which may be carried restrict the amount of power supply available. The weight limitation does not become important except during extremely deep dives. Another advantage of the externally mounted power supply is the elimination of the need to carry high currents through the wall of the cabin. With the primary power supply outside the cabin only small control currents are required for even the heavy duty propulsion motors. Small control wires may be used, which require less space in the available penetration and eliminate heavy power cables inside the cabin. The present size and number of penetrations in the cabin are fixed, and as more and more scientific equipment is added, more cabin space and penetration are required.

These factors, the extreme urgency of acquiring a larger power supply, and the much lower cost of lead-acid batteries prompted the initiation of the tests which will be detailed in this report.

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[1]Navy Electronics Laboratory Report 941, The 1957 Diving Program of the Bathyscaph TRIESTE, by A. B. Rechnitzer, 28 December 1959.

It should be noted here that the French bathyscaph, FNRS-3, has had some degree of success in operating with externally carried batteries, but because there is a lack of information concerning their methods of operation and because their dives have been limited to depths of less than 14,000 feet, it was decided to complete a full series of tests to evaluate this type of power supply.

TEST CONSIDERATIONS

It was necessary to insulate the batteries from the water to prevent shorting and to keep the water from mixing with the electrolyte. It was also necessary to transmit pressure from the water through the insulation to the electrolyte and thus throughout the battery to prevent the casing from collapsing. This was accomplished by placing the battery in an oil filled case as shown in figure 1. As the oil and the electrolyte compress due to pressure, water flows into the bottom of the case through the equalizing tube, thus retaining a balance of internal and external pressures. Compressibility tests on the transformer oil used as the insulating fluid show a volume loss of only 4.7 per cent at 16,000 psi. Since electrolyte is even less compressible, the water level in the bottom of the case could not rise high enough to short the battery as long as at least 5 per cent of the case volume in addition to that occupied by the battery itself is located below the battery top. In the final design of the operational battery cases, the batteries are supported several inches above the bottom of the case so that the water can never reach the bottom of the battery even in the deepest dives.

Because battery electrolyte in the fully charged state (specific gravity 1.260) sustains a volume loss of 3 per cent at 16,000 psi, it is necessary to provide a small reservoir of electrolyte above the top of the battery plates to prevent oil from coming in contact with the plates when the electrolyte compresses. The batteries used in the laboratory tests already contained a large enough void area above the plates to contain the needed additional volume of electrolyte, as can be seen in figure 2. The standard Navy 12-volt automobile batteries which were obtained for operational use, however, required an additional reservoir. This was provided for by attaching small polyethylene bottles to the top of each cell in place of the filling cap, as shown in figure 3.

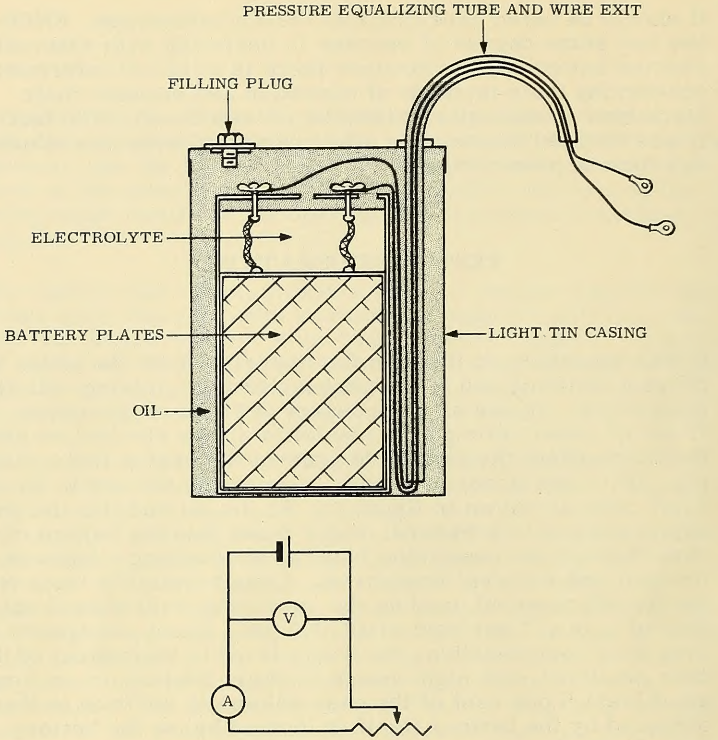

Figure 1. Schematic cross-section of battery and test case.

Because the size of the pressure test facility was limited (6 inches in diameter), smaller batteries were used during the test program than were actually used operationally. Since the general characteristics of lead-acid batteries are similar, it was not felt that this substitution imposed any serious limitations on the tests. Three identical Willard, 2-volt, 20 ampere-hour, lead-acid cells were used. These cells were labeled "A," "B," and "C," and will be so referred to in this report.

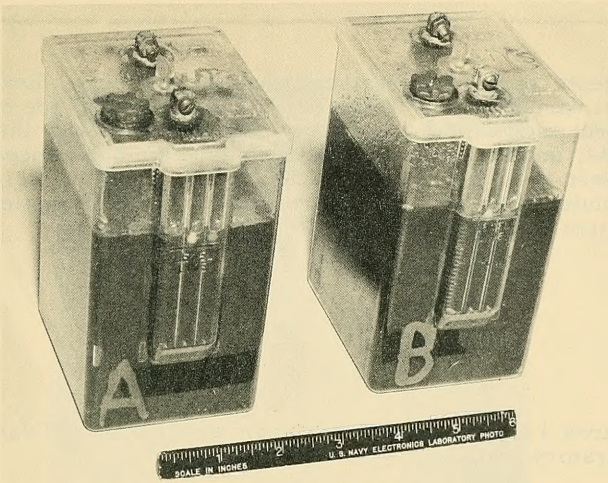

Figure 2. Photograph of Willard batteries used in tests.

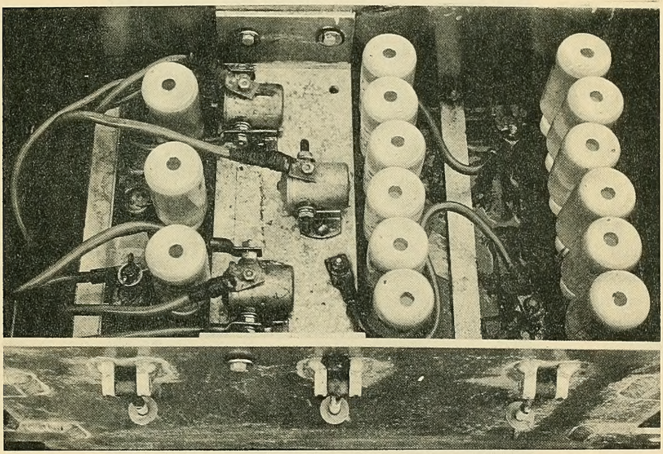

Figure 3. Interior view of battery box used during Project NEKTON II.

All tests were run under continuous supervision. Readings of all variables were taken every 15 minutes. Since both control and test readings were made with the same instruments, and the factors of interest were the differences between these readings, no attempt was made to obtain absolute calibration of the instruments. The estimated, relative accuracy of the readings is given below:

Pressure	± 500 psi
Temperature	± 1/4° F
Voltage	± 0.005 volt
Current	± 0.05 ampere

Figures 4 and 5 show the pressure equipment used during laboratory tests.

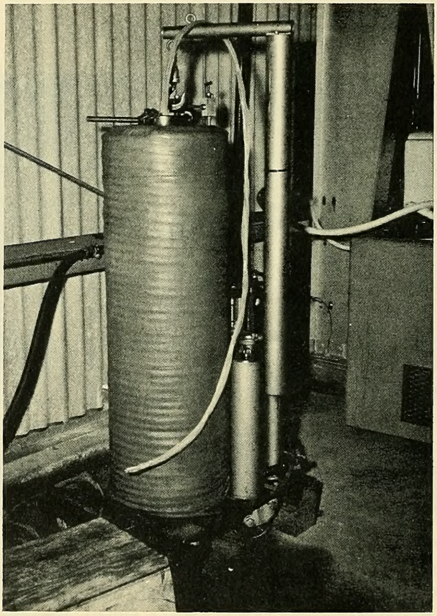

Figure 4. Pressure chamber used in tests.

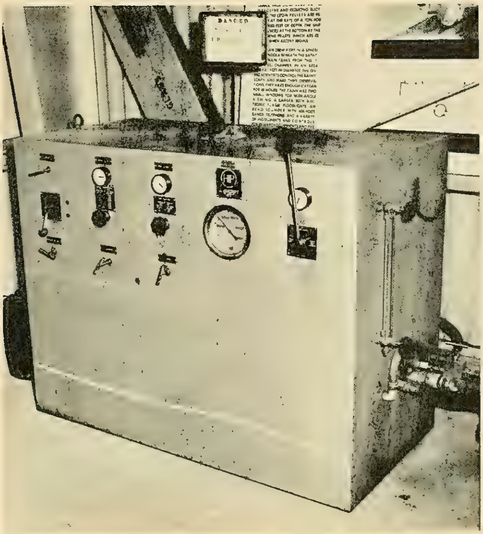

Figure 5. Control board for pressure chamber.

TEST PROGRAM

The first tests of lead-acid batteries were conducted as part of an operational dive of the bathyscaph. Two 12-volt and one 6-volt automobile batteries were obtained and encapsulated, using the methods discussed above and shown in figures 3 and 6. These batteries were wired through means of relays actuated from within the cabin to power two experimental plankton samplers. The batteries functioned very well to depths of over 19, 000 feet but were not used extensively because the plankton samplers malfunctioned.

After these tests the batteries were allowed to remain in their oil bath for some time, and it was discovered that the oil was slowly dissolving the "tar" used to seal the battery tops. This problem has been solved in succeeding tests by coating the battery tops with an epoxy resin which prevents the oil from carrying away the sealant.

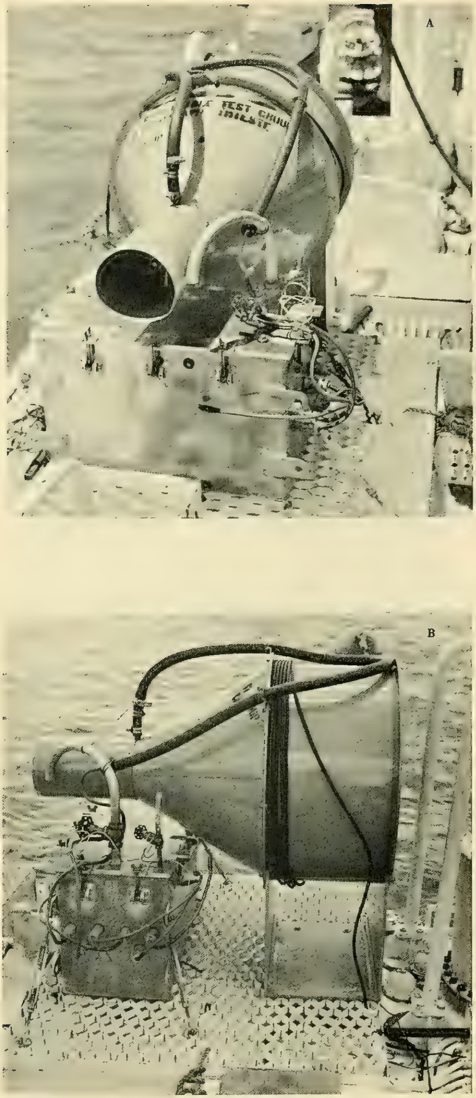

Figure 6. Exterior views of battery box used during Project NEKTON II.

The first laboratory tests were run on the Willard cells in October 1960. They were run primarily to gain familiarity with the factors involved and are therefore not detailed here. The significant tests which are detailed in this report (fig. 7-12) began in November 1960 and continued through January 1961, as shown in table I.

Tests 1, 3, 9, 12 and 13 were conducted in the battery shop under normal atmospheric conditions of temperature and pressure.

Tests 2 and 4 were conducted under conditions simulating a stay of 8 hours at a depth of 36,000 feet. Tests 5 and 6 were conducted to simulate dives to a depth of 24,000 feet, as shown in figure 7.

Test 7 was run to determine the IR drop in the added length of wire, necessitated by the length of the pressure chamber, used in tests 2, 4, 5 and 6. This correction was applied to data of tests 1 and 3 before graphing. Equal lengths of wire were used in all succeeding tests.

After the results of the first six tests were tabulated and compared, it was considered desirable to obtain curves which would reflect the complete capacity of the batteries. This had to be done within the normal limits of a working day; therefore, tests 8 and 9 were run to determine the discharge rate necessary to reach the low voltage limit of the batteries within 7-1/2 hours. Test 9 also served as the control discharge for battery "A" for the 3.5-ampere rate.

Tests 10 and 11 simulated capacity discharges at a depth of 36,000 feet. At the conclusion of each of these tests the pressure was removed from the test chamber as rapidly as possible (about 15 seconds). This rapid pressure release simulated a far more rapid rise to the surface than would ever be actually possible with the bathyscaph. The cell was immediately removed from the chamber and examined carefully. No evidence of damage to the plates from rapidly forming and expanding gases was noted, and subsequent discharges indicated no loss in capacity. Test 12 was run as a control.

Tests 13 and 14 were run to determine the operability of a nickel-cadmium cell under the same conditions.

Test number 15 was run to determine the possibility of delayed effects of operating under pressure and rapid decompression. No losses were noted.

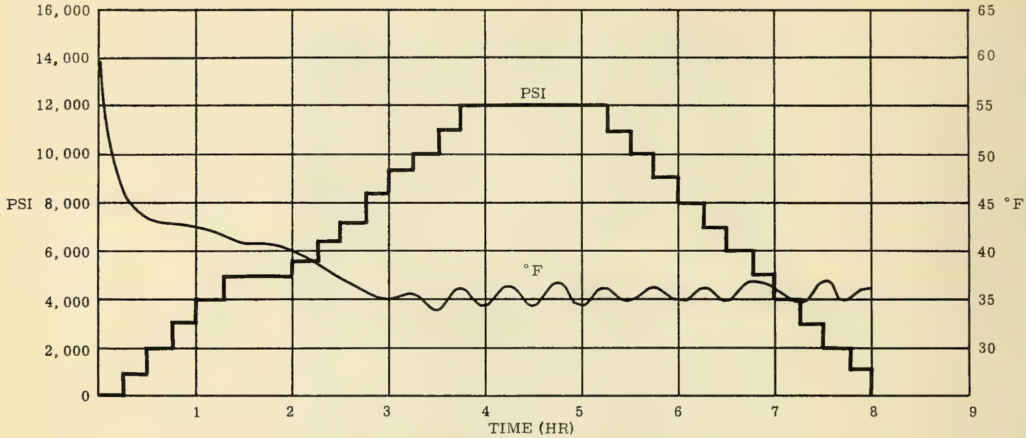

Figure 7. Graph of pressure and temperature variations programmed during simulated dives to 24,000 feet.

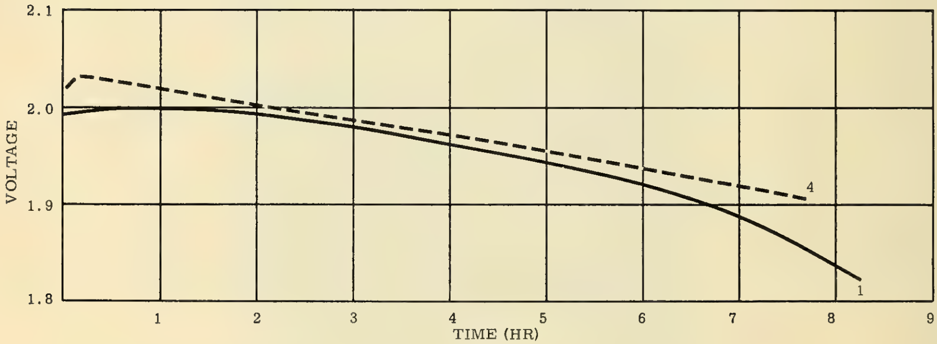

Figure 8. Graph of tests 1 and 4.

Test 1. Normal discharge of battery A at 2.5 amperes for control.

Test 4. 2.5-ampere discharge of battery A under 16,000 psi at 35-45° F.

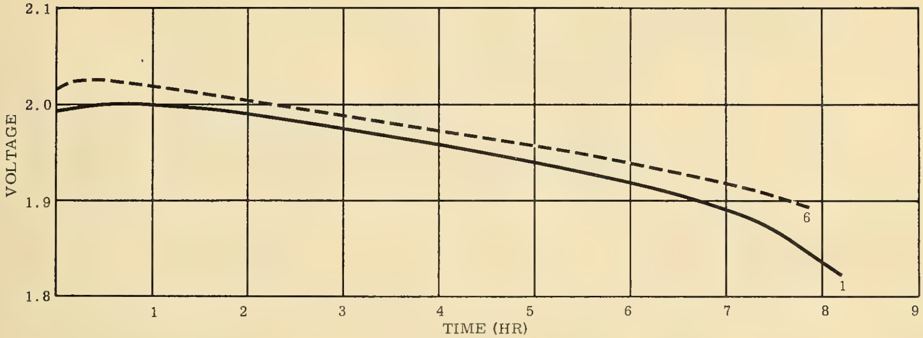

Figure 9. Graph of tests 1 and 6.
Test 1. Normal discharge of battery A at 2.5 amperes for control.
Test 6. 2.5-ampere discharge of battery A under conditions simulating a dive to 24, 000 feet.

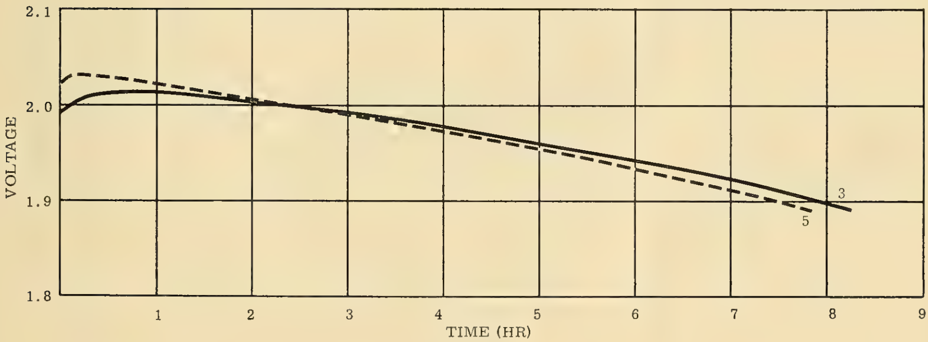

Figure 10. Graph of tests 3 and 5.
Test 3. Normal discharge of battery B at 2.5 amperes for control.
Test 5. 2.5-ampere discharge of battery B under conditions simulating a dive to 24, 000 feet.

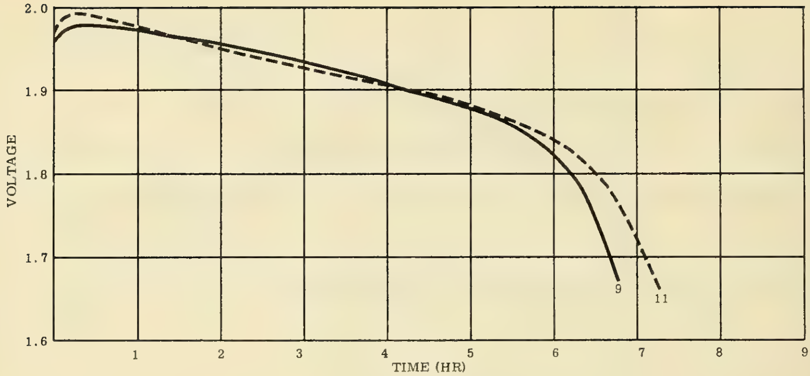

Figure 11. Graph of tests 9 and 11.
Test 9. Normal discharge of battery A at 3.5 amperes for control.
Test 11. 3.5-ampere discharge of battery A under conditions simulating submergence to 36,000 feet.

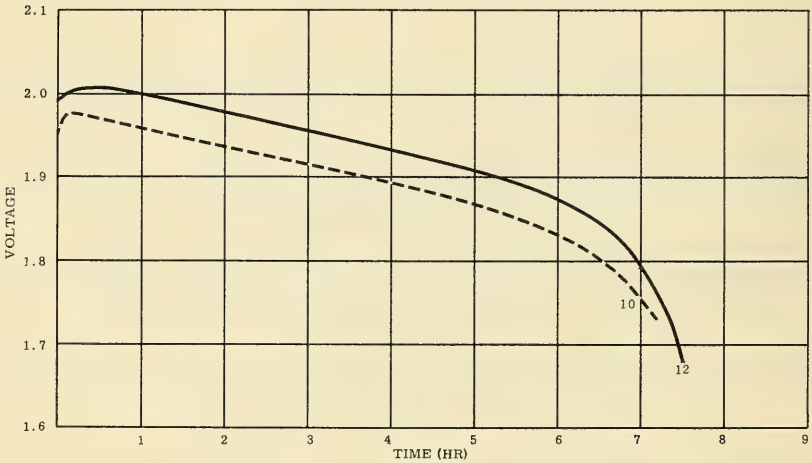

Figure 12. Graph of tests 10 and 12.
Test 10. 3.5-ampere discharge of battery B under conditions simulating submergence to 36,000 feet.
Test 12. Normal discharge of battery B at 3.5 amperes for control.

TABLE I. SCHEDULE OF PRESSURE TESTS.

Test No.	Date (1960-61)	Batt.	Rate of Disch. (amp)	Press.	Temp. (°F)	Disch. Duration (hr:min)	Remarks
1	8 Nov	A	2.5	Atmos	71	8:15	
2	9 Nov	B	2.5	16000	37-43	8:10	Test considered invalid because battery inadvertently shorted prior to start of test. No graph.
3	14 Nov	B	2.5	Atmos	73	8:45	
4	15 Nov	A	2.5	16000	35-45	8:15	
5	16 Nov	B	2.5	See pressure-temperature chart of simulated dive		7:52	
6	17 Nov	A	2.5			7:55	
7	18 Nov	C	2.5				Bench test to determine magnitude of error. (Lengths of test lead used during previous bench tests were different than those used in pressure chamber.)
8	21 Nov	A	3.0	Atmos	71	8:35	No graph plotted for this test.
9	28 Nov	A	3.5	Atmos	68	6:45	
10	29 Nov	B	3.5	16000	31-37	7:16	Rapid decompression test.
11	1 Dec	A	3.5	16000	32-39	7:05	" " "
12	2 Dec	B	3.5	Atmos	71	7:30	
13	14 Dec	NC	6.0	Atmos	68	6:20	
14	22 Dec	NC	6.0	16000	31-46	6:01	
15	4 Jan	A	3.5	Atmos	68	7:15	This test discharge was run to determine delayed effects of rapid decompression from test 11. None noted.

DISCUSSION

Although minor fluctuations may be noted in the voltages of the cells, there is no consistent decrease in capacity and it is believed that these voltage fluctuations can be accounted for in the normal fluctuation found in any lead-acid cell from one charge to the next. It should be noted that in some cases the apparent capacity under high pressure and low temperature conditions is actually greater than that found in the control discharges and that in every case except one, the discharge curve, under pressure, is actually flatter than the control curve. It is also interesting to note that during the time that the pressure is being applied, there is an initial voltage rise significantly higher than normally encountered. This is probably due to the compression and virtual elimination of the gas bubbles or film on the face of the battery plates.

Based on the results of these tests, construction of battery boxes (fig. 13) was begun and sufficient 12-volt automobile batteries for two complete operational sets (1400 ampere-hours at 24 volts per set) were obtained. These batteries were coated with epoxy resin and fitted with the polyethylene reservoir previously mentioned (fig. 14). They have now been placed in service and presently are providing a satisfactory primary power supply for the TRIESTE.

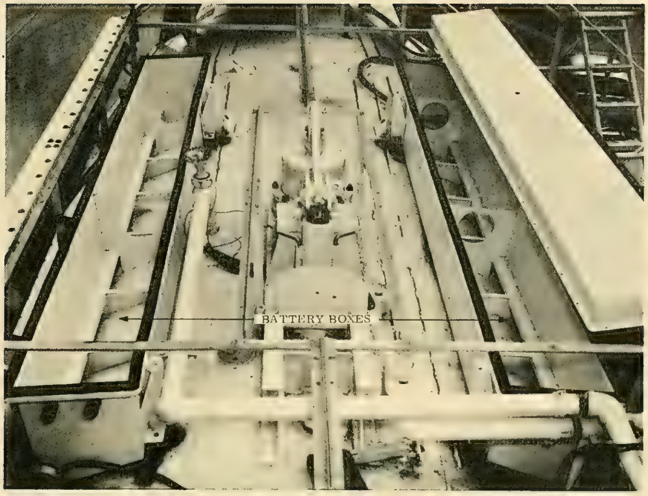

Figure 13. New battery boxes installed on TRIESTE.

Figure 14. Navy standard battery as modified for use on TRIESTE.

CONCLUSION

The tests show that it is practical to use lead-acid batteries in pressure-equalized, oil-filled cases as the primary power supply for the bathyscaph or any other deep experimental submersible craft that can handle their weight. The pressures and temperatures encountered in the oceans, to any depth, have no significant effect on lead-acid battery operation, capacity, or rate of discharge.

RECOMMENDATIONS

1. Use externally carried lead-acid storage batteries as the primary power supply for the TRIESTE.

2. Extend the investigations reported herein to include other types of "wet" batteries for similar uses.

3. Initiate investigation to determine other areas of use for this type of power supply, such as unmanned buoys or ocean-bottom instruments.

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Lead-acid storage batteries were found to provide an effective and practical power source under pressures up to 16,000 psi and temperatures down to 35° F. They are cheaper than silver-zinc cells and may be mounted externally to save cabin space. Report recommends them on TRIESTE and recommends extending investigations to include other types of "wet" batteries for similar uses.

Charts and illustrations provide information about battery performance, installation, and testing procedure.

1. Bathyscaphs - Power supply
2. TRIESTE - Power supplies
3. Wet batteries - Applications

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